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Some chemical and physical characteristics of skidroads and adjacent undisturbed soils

R.B. Smith and E.F. Wass

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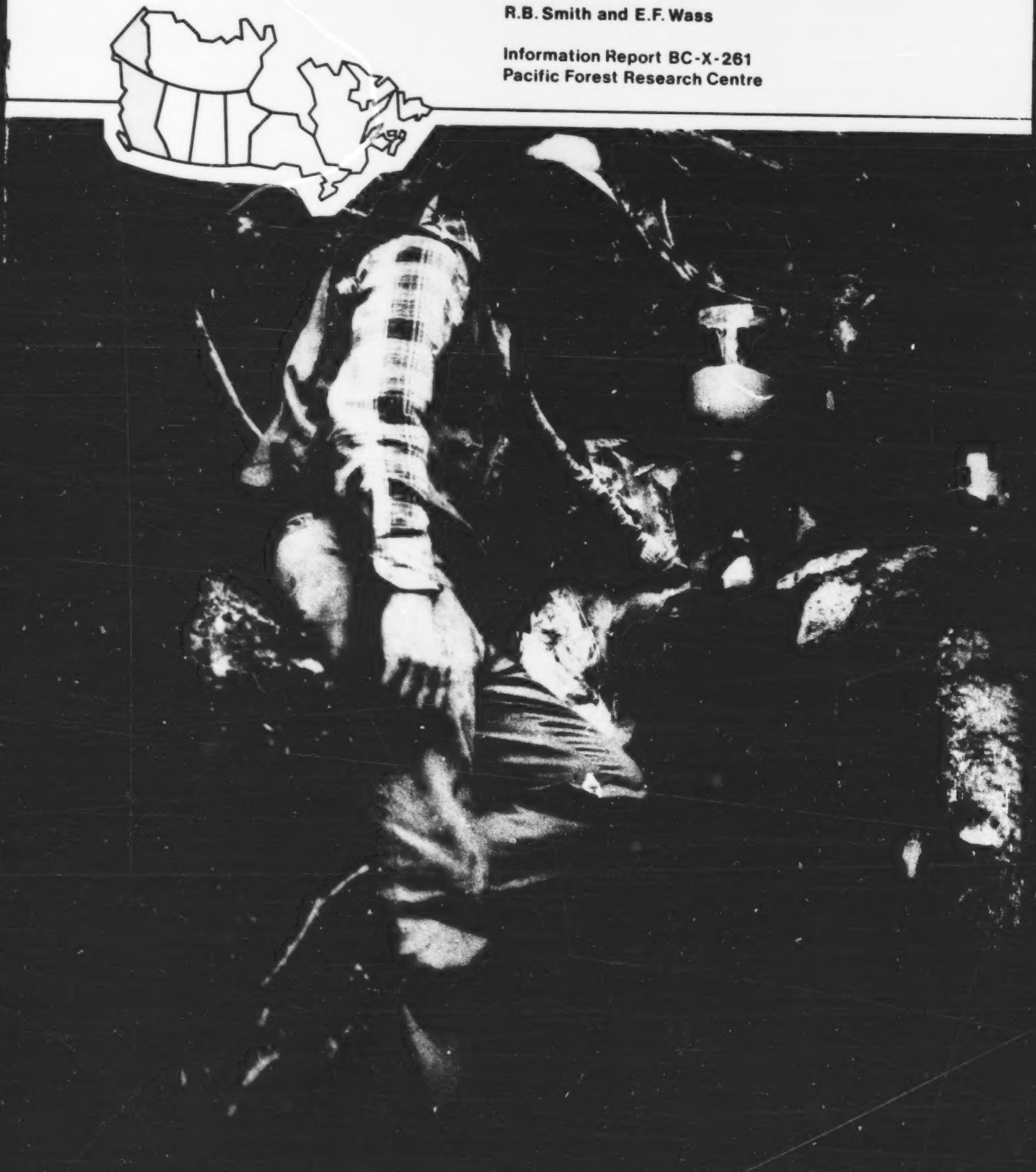

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Cover: Measuring bulk density in undisturbed soil above a skidroad

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Abstract

Contour skidroads and adjacent undisturbed soils in five steep clearcuts 17 to 23 years of age and located in southern interior British Columbia were selected for studies of soil characteristics. Trenching, soil sampling and analyses, penetrometer tests, bulk density and soil temperature measurements were used to explain previously described tree-growth patterns and to aid future rehabilitation efforts.

Soils varied from strongly acid to alkaline and from coarse to medium texture. In undisturbed soils, bulk density and pH increased while organic carbon, total nitrogen and fine soil fraction decreased with depth. The inner, gouged portions of skidroads reflected the increase in bulk density with depth with their relatively dense soils and high resistance to penetration. These physical conditions, in addition to relatively low organic matter and nitrogen contents, play a large role in reduced growth rates of trees established at this skidroad position. Greater height growth on the outer half of skidroads was related mainly to the less compact soils. Poor growth of trees across the whole skidroad profile on alkaline soils was attributed to a nutritional imbalance aggravated by the absence of surface organic horizons which normally provide a carbonate-free haven for roots.

The study indicated a slow rate of amelioration of disturbed soils, particularly in terms of density, penetrability, carbonate concentration and pH, but marked increases in organic carbon and total nitrogen as natural revegetation proceeds over a 20-year period.

Résumé

Les caractéristiques du sol dans des chemins de débardage suivant les lignes de niveau et des terrains non perturbés adjacents ont été étudiées dans cinq parcelles en pente ayant subi des coupes rases il y a 17 à 23 ans et se trouvant dans la partie sud de l'intérieur de la Colombie-Britannique. Des tranchées ont été creusées, des échantillons de sol été prélevés et analysés, des tests ont été effectués à l'aide d'un pénétromètre, et la masse volumique apparente ainsi que la température du sol ont été mesurées afin d'expliquer les modes de croissance des arbres décrits antérieurement et d'aider les futurs efforts de restauration.

Les sols variaient de fortement acides à alcalins, et leur texture allait de grossière à moyenne. Dans les sols non perturbés, la masse volumique apparente et le pH augmentaient avec la profondeur, tandis que les teneurs en carbone organique et en azote total diminuaient, de même que la fraction fine. Les parties intérieures creusées des chemins, où le sol était relativement dense et présentait une forte résistance à la pénétration, reflétaient l'augmentation de la masse volumique apparente avec la profondeur. Ces caractéristiques physiques ainsi que les teneurs relativement faibles en matières organiques et en azote sont des facteurs importants de la croissance moins rapide des arbres poussant à cette position dans les chemins. La hauteur plus grande des arbres dans la moitié extérieure des chemins est attribuable principalement à la compacité plus faible du sol. La faible croissance des arbres sur tout le profil des chemins en sols alcalins a été attribuée à un déséquilibre nutritionnel, aggravé par l'absence d'horizons organiques en surface, lesquels procurent normalement aux racines une zone exempte de carbonates.

L'étude a indiqué une lente amélioration des sols perturbés, plus particulièrement en ce qui concerne la masse volumique, la pénétrabilité, la concentration en carbonates et le pH, mais une augmentation marquée des teneurs en carbone organique et en azote total an fur et à mesure de la régénération naturelle sur une période de 20 ans.

Table of contents

	Page
Abstract/Résumé	3
Introduction	6
Methods	7
Study sites	7
Skidroad selection and dimensions	7
Trenching and soil sampling	8
Bulk density	8
Penetrability	9
Temperature	9
Soil sample analyses	9
Statistical analyses	9
Results	9
Undisturbed soils	9
Bulk density	10
Resistance to penetration	12
Total nitrogen	13
Organic carbon	13
Carbon/nitrogen ratio	14
Acidity	14
Free carbonates	14
Coarse fragments	14
Temperature	14
Discussion	14
Conclusions	16
Acknowledgements	17
Literature Cited	17
Tables	19

Fig. 1. A steep ground-skidded clearcut with contour skidroads.

Introduction

Ground skidding is the major logging system in British Columbia east of the Coast Mountains and is routinely applied on slopes with gradients in excess of 40% (Wellburn 1975). On such slopes, the skidroads normally are built close to the contour to provide a safe running surface for yarding vehicles (Fig. 1). Construction of contour skidroads on steep slopes entails deep gouging of the soil and its displacement outwards as fill and sidecast. In the Nelson Forest Region of British Columbia, an average of over 32% of sampled clearcuts yarded on bare ground consisted of skidroads (Smith and Wass 1976). Soil exposed on the inside of the skidroads often has different characteristics than the upper, undisturbed layers (Dyrness 1965; Gent *et al.* 1983). Even when this soil is mixed with topsoil an influence on subsequent tree establishment and growth would be expected. In addition, mechanical compaction by construction and yarding equipment further differentiates skidroad surfaces from undisturbed soils. Tree growth rates were generally lower for trees on the inner half than on the outer half of skidroads in interior British Columbia (Smith and Wass 1979, 1980). A soil sensitivity rating scheme was developed using general soil and climatic characteristics as an aid to the development of environmentally acceptable logging systems (Smith and Wass 1980). However, we still lack the knowledge required to justify or effectively plan such rehabilitative measures as ripping, fertilizing and grass and legume seeding on a site-specific basis (Megahan 1977; Carr 1980). This study of specific skidroad soil characteristics was undertaken to aid in the planning of rehabilitative operations on skidroads.

Methods

Study sites

Five of the 15 sites on which tree growth studies were conducted previously (Smith and Wass 1979, 1980) were chosen for detailed soil studies (Table 1). Four were located in the Nelson Forest Region and one in the Cariboo Forest Region (Fig. 2). They were chosen, on the basis of earlier work, to represent a range of soil and climatic conditions and a variety of tree-growth responses (Tables 1, 2).

Skidroad selection and dimensions

On each of the five clearcuts, three contour skidroad segments (15 to 20 m in length) were chosen within the top, middle and lower portions of the clearcuts. These were considered representative of the larger number of segments used in the earlier growth studies. The widths and slopes of the sidecast, road bed and cutbank were recorded. Specific widths of the berm, outer track, mid-road and inner track were measured. These measurements along with those of distances to the buried surface soil were used to calculate cross-sectional areas (Table 3). The total

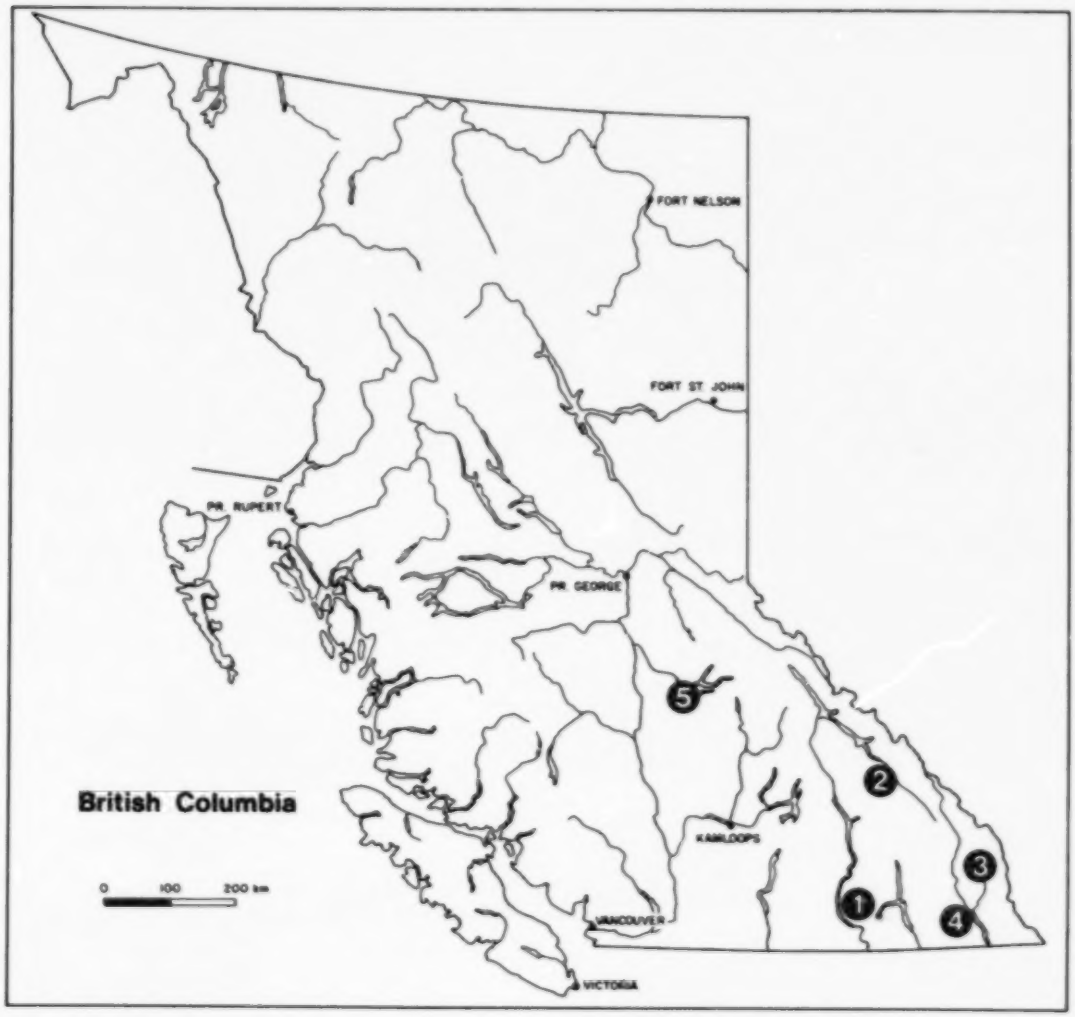

Fig. 2. Locations of study areas. 1 = Russell Creek; 2 = Templeton Creek; 3 = Inlet Creek; 4 = Gold Fire; 5 = Vunder Fire.

average width of about 8 m consisted of somewhat less than half as road surface and the remainder as cutbank and sidecast or fill slope. The average volume of cut material for all skidroads was 1.08 m^3 per lineal m of skidroad. Depths of cuts at the inner track averaged less than 0.5 m whereas deposits as measured at the berm averaged somewhat more (Table 3).

Trenching and soil sampling

For each skidroad segment, a trench was dug from the bottom of the sidecast across the skidroad and into the cutbank (Fig. 3). Each trench was dug sufficiently deep to reveal the buried, original soil surface and additionally, if necessary, to a total depth of not less than 75 cm (Fig. 4). A string was attached at the surface of the buried horizon and stretched tautly to the top of the undisturbed profile above the cutbank. This allowed estimates of the depth of material removed from various points along the gouged portion of the skidroad. Soil sampling and profile descriptions proceeded along the trench walls as follows:

Berm. The disturbed soil down to the buried original surface was described (Canada Soil Survey Committee 1978) and samples were collected from the 0- to 10-cm, 10- to 20-cm, and 20- to 30-cm layers and at 30-cm intervals thereafter. The depth to the original surface was measured.

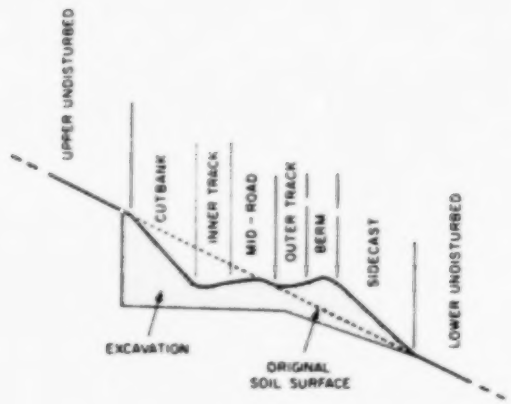

Fig. 3. Skidroad disturbance classification system, location of original soil surface and area of excavated trench.

Fig. 4. Original soil surface buried by skidroad fill material at berm.

Outer track. Samples were taken at the 0- to 10-cm, and 10- to 20-cm layers. The distance down to the original surface was measured.

Mid-road and inner track. Soil samples were collected at the 0- to 10-cm, 10- to 20-cm, and 20- to 30-cm layers. The distance down to or up to the original surface was measured.

Undisturbed. A complete profile description was made. Samples were taken at the 0- to 10-cm, 10- to 20-cm, 20- to 30-cm, 30- to 60-cm, and 60- to 90-cm layers and deeper, if required, to reach a depth equivalent to that of the gouged inner track plus an additional 75 cm.

Bulk density

The bulk density of soil was measured with an excavation/ displacement procedure using a sand-funnel apparatus (Blake 1965). Bulk densi-

ties were calculated on an oven-dry basis for the whole soil sample and for the fraction less than 2 mm by correcting for the volume occupied by rock fragments.

For each skidroad segment, bulk densities were determined for two replicates in the 0- to 10-cm layer and in the 10- to 20-cm layer in the berm, outer track, mid-road, inner track and in the undisturbed soil above the skidroads (Fig. 3). Additionally, bulk densities were measured in the undisturbed soil at a depth judged to be equivalent to the depth of soil displaced at the inner track, and of surface organic horizons (FH layers).

Penetrability

A proving ring, cone penetrometer (U.S. Corps of Engineers, Model CN-973) equipped with a 3.2-cm^2 cone was used to measure resistance to penetration at the berm, outer track, mid-road, inner track and in the upper undisturbed soil. Readings were taken as the probe passed the 2.5-cm level starting at the surface of mineral soil. A similar reading was taken in holes excavated to a depth of 10 cm, i.e., at the 12.5-cm level. Eight replicates of each probe were made in each of the three skidroad segments at each site.

Temperature

Soil temperatures were measured at a depth of 10 cm with either dial-head, soil probe thermometers or glass thermometers placed in pre-punched holes. Thermometers were placed 2 m above the top of the cutbank and below the bottom of the sidecast and at the middle of the cutbank, inner track, berm and sidecast. Air temperature was measured in the shade. Readings were taken as close as possible to 0900, 1230 and 1600 hrs over the two to three days required to complete studies at each skidroad segment.

Soil sample analyses

Acidity. The pH of all samples was determined potentiometrically in a 0.01 M $CaCl_2$ solution (McMullan 1971).

Carbonate. The presence of free carbonates was indicated by using dilute HCl (Walmsley *et al.* 1980). The content of carbonate carbon was determined gravimetrically for the fraction less than 2 mm with an HCl-$FeCl_2$ solution (McKeague 1978).

Organic carbon. Organic carbon content was determined for the fraction less than 2 mm by the Walkley-Black method (Allison 1965) for samples with carbonate carbon and by the LECO Induction Furnace method (McKeague 1978) for all other samples.

Total nitrogen. Total nitrogen content for all samples was determined for the fraction less than 2 mm by an automated, semi-micro Kjeldahl method (McKeague 1978).

Particle size. Samples were sieved and the fraction greater than 2 mm was weighed and expressed as a percentage of the total sample weight. Texture of the fine fraction of selected samples was determined by the Bouyoucos hydrometer method (McKeague 1978).

Statistical analyses

Data were subjected to Student-Newman-Keuls' multiple range tests (Zar 1974) to determine the significance of differences in soil properties among the skidroad components and the undisturbed soils.

Results

Undisturbed soils

Undisturbed soils varied greatly in general chemical and physical characteristics (Tables 1, 2). In three of the study sites (Inlet, Templeton and Russell), an FH horizon 4 to 9 cm thick was present (Table 7), whereas in the burned sites (Vunder and Gold) there was little or no FH layer. Marked differences in physical and chemical properties occurred with increasing depth within specific, undisturbed profiles. Bulk density generally increased with depth (Figs. 5a, 5b). Organic carbon content of mineral soil decreased with depth sharply to about 20 cm then more

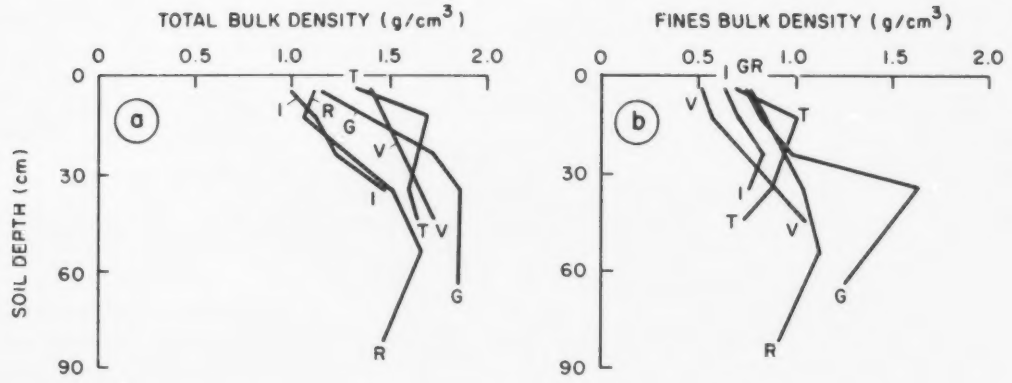

Fig. 5. Variation in bulk density with depth in undisturbed mineral soil at five sites. 5a = Total soil; 5b = Fine fraction. R = Russell; T = Templeton; I = Inlet; G = Gold; V = Vunder.

gradually to 100 cm (Fig. 6). Percentage total nitrogen followed the pattern of organic carbon by decreasing with depth (Fig. 7). In four of five sites, pH values generally increased with depth but only slightly in the most acid soils at Russell (Fig. 8). In the two burned sites (Vunder and Gold), surface (0 to 10 cm) pH was higher than the pH in the 10- to 20-cm layer. The opposite trend occurred at the three unburned sites. Soil at the Inlet site had pH values markedly higher than all other soils. This reflected the presence of carbonate carbon close to the surface and its increasing content downward (Fig. 9). Coarse fragment content generally increased with depth but with marked fluctuations in the top 50 cm (Fig. 10). Clay content decreased with depth at the Russell, Templeton and Inlet sites and silt content decreased with depth at the Gold, Russell and Templeton sites (Figs. 11, 12). Sand content increased with depth at all areas but the Vunder site (Fig. 13). Clay and silt contents were particularly low at the Russell site and high at the Inlet site.

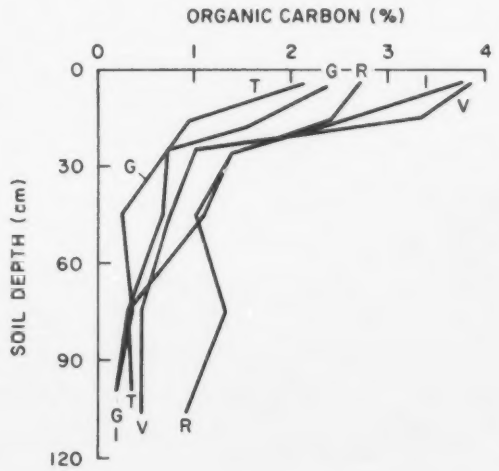

Fig. 6. Variation of percent organic carbon with depth in undisturbed mineral soil at five sites. R = Russell; T = Templeton; I = Inlet; G = Gold; V = Vunder.

Bulk density

Significantly higher bulk densities occurred in the surface 0- to 10-cm and 10- to 20-cm layers for both the whole soil and the fine (less than 2 mm) fraction at the inner track than in the undisturbed soil at four of the five sites studied (Table 4). At the Templeton site there were no significant differences in any bulk density comparisons. The inner track was also more compact than the mid-road, outer track and berm in a number of soil fraction/depth/site comparisons (Table 4). Some of the latter three skidroad categories at the Inlet, Gold and Vunder sites had denser soils than the undisturbed soil for several fraction/depth combinations (Table 4). Bulk densities

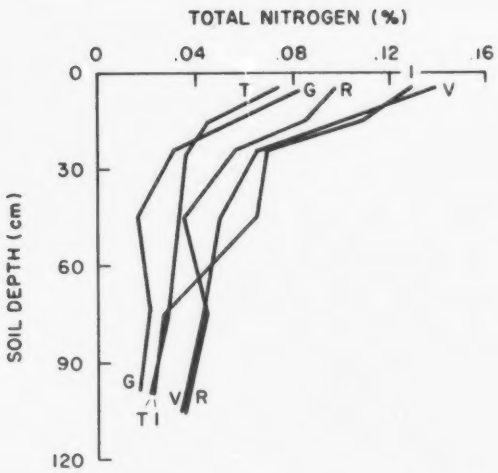

Fig. 7. Variation of percent total nitrogen with depth in undisturbed mineral soil at five sites. R = Russell; T = Templeton; I = Inlet; G = Gold; V = Vunder.

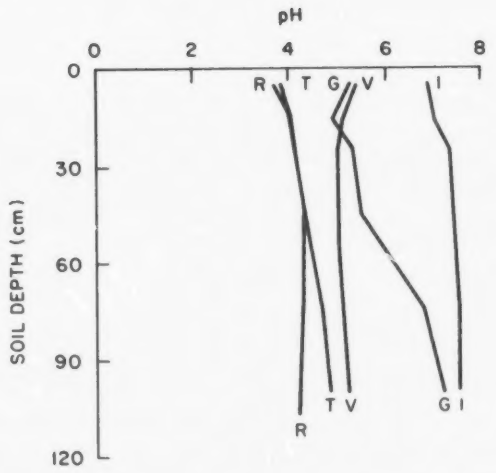

Fig. 8. Variation of pH with depth in undisturbed mineral soil at five sites. R = Russell; T = Templeton; I = Inlet; G = Gold; V = Vunder.

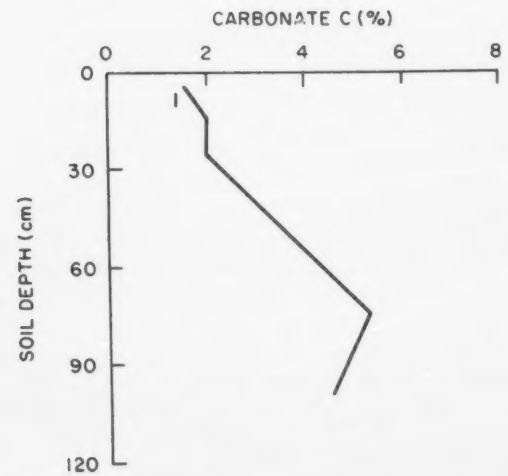

Fig. 9. Variation of percent carbonate carbon with depth in undisturbed mineral soil at the Inlet site.

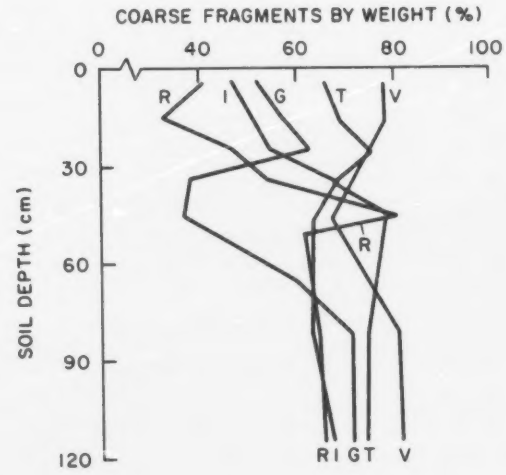

Fig. 10. Variation in percent coarse fragments by weight with depth in undisturbed mineral soil at five sites. R = Russell; T = Templeton; I = Inlet; G = Gold; V = Vunder.

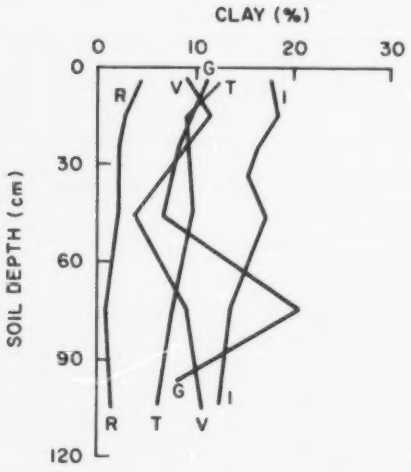

Fig. 11. Variation of percent clay with depth in undisturbed mineral soil at five sites. R = Russell; T = Templeton; I = Inlet; G = Gold; V = Vunder.

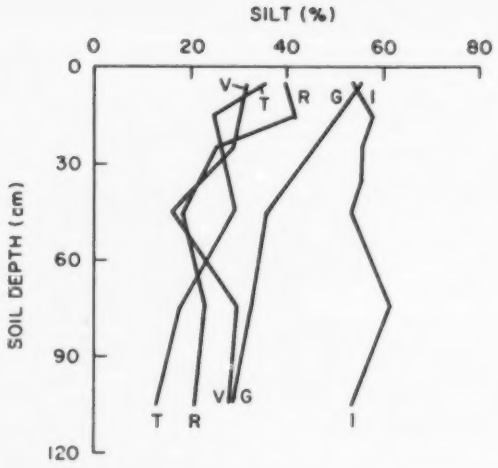

Fig. 12. Variation of percent silt with depth in undisturbed mineral soil at five sites. R = Russell; T = Templeton; I = Inlet; G = Gold; V = Vunder.

were not generally different between upper (0- to 10-cm) and lower (10- to 20-cm) layers and, where significant differences did occur, the trends were not consistent. Skidroad bulk densities exceeded those in the undisturbed by the largest margin at the Vunder site and by the least at the Russell and Templeton sites.

Bulk densities tended to be higher at the surface of the inner track than at the same depth below the original surface in the undisturbed soil at the base of the cutbank, significantly so only for the fine fraction at the Inlet site (Table 5).

Resistance to penetration

Resistance to penetration was significantly higher on the inner track, mid-road and outer track than in the undisturbed soil for all sites and for both the 2.5-cm and 12.5-cm levels (Table 6). In addition, berms showed higher resistance to penetration than the undisturbed in 8 of 10 depth/location combinations (Table 6). Of the skidroad components, the inner track was least penetrable, the mid-road and outer track of intermediate penetrability and the berm was most penetrable. The largest increase in resistance to penetration on the skidroads relative to the un-

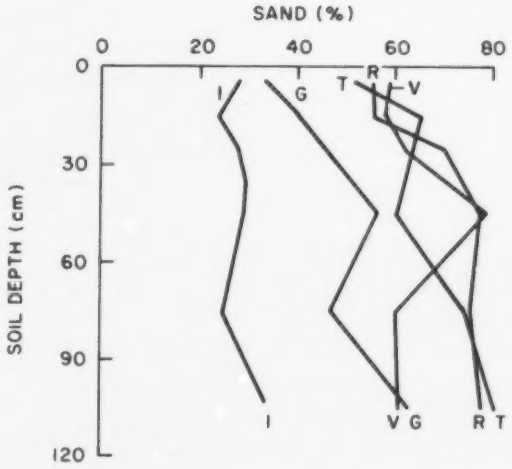

Fig. 13. Variation of percent sand with depth in undisturbed mineral soil at five sites. R = Russell; T = Templeton; I = Inlet; G = Gold; V = Vunder.

disturbed occurred in the Inlet site and the least at the Russell site.

Total nitrogen

The total nitrogen content by soil weight of FH horizons was much higher than for all other surface (0- to 10-cm) mineral soil layers at the same sites (Table 7). When calculated on a soil volume basis as kilograms per hectare, amounts of nitrogen in the FH layer were generally higher than for 0- to 10-cm mineral soil layers at the Inlet and Templeton sites but less at the Russell site (Table 7).

Calculation of total nitrogen on a soil volume basis for the top 20 cm, including any humus present, showed significantly higher levels for the undisturbed soil at the Inlet site than for most skidroad components (Table 8). The reverse was true at the Gold and Vunder sites. There were no significant differences in total nitrogen content between the top 20 cm of skidroad and the top 20 cm of undisturbed soil at the Russell or Templeton sites.

Percentages of total nitrogen by soil weight in the undisturbed mineral soil were either not significantly different or, in a few cases, were significantly higher at the 0- to 10-cm and the 10- to 20-cm layers than in the inner track, mid-road and outer track (Table 7). In some sites, a significantly higher content of nitrogen occurred in the berm, mid-road and outer track than in the inner track. Below 20 cm, particularly in the 30- to 60-cm layer, the percentage of nitrogen was consistently higher in the berm than at equivalent depths in the undisturbed soil (Table 9).

On a soil volume basis, significantly higher levels of nitrogen appeared for many skidroad components than for the undisturbed soil (Table 7). Any significant differences among skidroad components involved low nitrogen in the inner track. Nitrogen expressed on either a weight or volume basis was generally higher in the 0- to 10-cm layer than in the 10- to 20-cm layer, significantly so for a number of combinations (Table 10).

Levels of total nitrogen were significantly higher in three sites on a soil weight basis and three sites on a soil volume basis in the inner track compared with the same depth below the original surface in the undisturbed soil (Table 5).

Organic carbon

FH horizons present in undisturbed profiles in three sites contained an average of 24 to 40% organic carbon, all significantly higher than for any other layer at each location (Table 7). When calculated on the basis of soil volume, the weight of organic carbon per hectare in FH layers was higher than for all surface (0- to 10-cm) mineral soil layers at two of the three sites (Table 7).

The weight of organic carbon per hectare in the top 20 cm, including any humus present, was higher for the undisturbed soil at the Inlet site than for most skidroad components (Table 8). The opposite was true at the Gold and Vunder sites. There were no significant differences in the organic carbon content between the top 20 cm of skidroad and the top 20 cm of undisturbed soil at the Russell or Templeton sites.

On the basis of soil weight, organic carbon contents of the 0- to 10-cm and 10- to 20-cm layers in some inner track and mid-road depth/site combinations were significantly lower than those at the same depths in the undisturbed mineral soil (Table 7). Organic carbon generally increased from the inner track outwards to the berm. At lower levels, particularly below 30 cm, the organic carbon content was significantly higher in the berm than at the same depth in undisturbed soil in four of the five sites (Table 9).

When computed on a soil volume basis, the organic carbon contents of the berm, outer track and mid-road components were frequently significantly higher than in the undisturbed soil (Table 7). There were generally higher levels of organic carbon on the basis of both soil weight and volume in the top 10 cm of mineral soil than in the 10- to 20-cm layer but significantly so only for a few combinations (Table 10).

Levels of organic carbon were significantly higher in three sites on the basis of soil weight and three sites on the basis of soil volume in the inner track compared with the same depth below the original surface in the undisturbed soil (Table 5).

Carbon/nitrogen ratio

Carbon/nitrogen (C/N) ratios were relatively uniform throughout undisturbed and skidroad mineral soil layers. Ratios in FH horizons were, however, higher than those in mineral soil layers, particularly at the Templeton site (Table 7).

Acidity

The most acid soils occurred at the Russell and Templeton sites and the most alkaline soils were at the Inlet site. In the three sites that had FH layers, this layer was more acid than 0- to 10-cm mineral soil layers in the undisturbed soil and in all skidroad components (Table 7). Except at the Vunder site, pH values were lower in the undisturbed, surface mineral soil than on the skidroad surfaces (Table 7). Some significant differences occurred among skidroad components but trends were not consistent. There were no significant differences in pH at any of the sites between the inner track and at the same depth below the original soil surface in undisturbed soil (Table 5).

Free carbonates

The percentage of carbonate carbon at the Inlet site was lowest at the mid-road, significantly so in the 0- to 10-cm and 10- to 20-cm layers than the other skidroad components using a natural log (X + 1) transformation (Table 11). There was no significant difference in content of carbonate carbon between the inner track and at the same depth below the original soil surface in undisturbed soil (Table 5).

Coarse fragments

Coarse (more than 2.0 mm) rock fragment contents of the skidroad components were not particularly different at the Vunder and Templeton sites but were markedly higher in the sidecast at the Inlet, Russell and Gold sites. The Vunder site had the highest coarse fragment content (69%) and the Russell site had the lowest (41%).

Temperature

Soil temperatures at a depth of 10 cm were generally higher on the skidroad than in the adjacent undisturbed soil (Table 12). Significantly higher average daily temperatures occurred in the berm for the Russell, Templeton, Gold and Vunder sites than in the undisturbed soil. Similarly, significantly higher temperatures occurred in some of the other skidroad components than the undisturbed soil (Table 12). The reverse, i.e., significantly higher temperatures in the undisturbed soil, did not occur at any of the five sites.

Discussion

The skidroads were similar in size to those reported for the southern interior of British Columbia by McMorland (1980). His average total width of 8.1 m was 0.2 m greater than ours. Our skidroads were thus representative of contour skidroads as built on sloping ground by conventional, large tractors (D-6 or equivalent). Such construction involved gouging to an average depth of over 40 cm at the inner track and deeper at the ditchline. An average of 1.08 m^3 of soil per lineal m of skidroad was displaced outwards and mixed to a varying degree before settling as fill or sidecast. Based on an average cover of skidroads of 32.3% (Smith and Wass 1976) and on the skidroad dimensions from this study, the estimated amount of soil displaced was 442 m^3/ha. This is in the same range as the 405 m^3/ha reported displaced on steep slopes in New Zealand during thinning operations (Leitch 1982).

The soil exposed by skidroad construction initially had characteristics similar to the undisturbed soil at the same (excavated) depth below the original surface with some differences resulting from the effects of vehicular traffic. These exposed soils had higher bulk density, higher resistance to penetration, lower total nitrogen and organic carbon contents, higher pH and higher coarse fragment content relative to the undisturbed mineral soil surface. The magnitude of these differences and their importance to tree productivity depends primarily on the nature of the original soil. For instance, subsoils at the Inlet and Vunder sites had markedly lower organic carbon and nitrogen contents than their surface

mineral soils, whereas the differences were much less at the Templeton and Gold sites. Truncation of soil profiles in the former two sites would tend to reduce the availability of organic matter proportionally more than in the latter sites. The bulk density of subsoil at the Gold site was much higher than that of the surface mineral soil but not greatly so at the Templeton site. These differences were reflected in skidroad characteristics in that there were much denser soils on skidroads at the Gold site than in undisturbed soils, whereas there was little difference in density between skidroad and undisturbed soil at the Templeton site. The pH of subsoil at the Inlet and Gold sites was particularly high and correspondingly high levels were recorded in the skidroad surfaces. In contrast, little difference in acidity occurred with soil depth at the Vunder site and pH levels were lower on the skidroads than in the surface, undisturbed mineral soils.

Considering the natural trends in soil characteristics with increasing depth, it is not unexpected that, for instance, higher pH levels and bulk densities were found at the base of cutbanks than in the upper, undisturbed mineral soil of newly excavated skidroads (Krag 1983). Seventeen to twenty-three years after skidroad construction, we found that bulk density (except at the Templeton site) and resistance to penetration remained significantly higher in the inner part of the road than in the upper, undisturbed mineral horizons. Bulk density in the inner part of the road, however, was generally not significantly different than at a depth in the undisturbed soil equivalent to the excavated inner track. If the inner skidroad soils were mechanically compacted, they did not recover beyond their original density, and in the case of the Inlet site, remained denser after mechanical compaction than they were originally. Such slow improvement in density has been noted by several authors (Perry 1964; Hatchell and Ralston 1971; Wert and Thomas 1981). Despite a high bulk density these inner skidroad soils had, after 17 to 23 years, organic carbon and total nitrogen contents that were significantly higher for the mineral soil 0- to 10-cm layer than in their original, unexposed state. In some sites they, in fact, approximated levels found in upper, undisturbed soils. Such increases in organic carbon on newly exposed soil are to be expected (Sondheim and Standish 1983) as a result of litterfall, root exudates, sloughing and death and soil faunal activity (Bormann and Likens 1979) and organic debris added during yarding operations. However, as indicated by low productivity (Smith and Wass 1979, 1980), the improved organic carbon and total nitrogen status did not compensate for the poor physical condition of the inner skidroad soils. Other authors (Forristall and Gessel 1955; Perry 1964; Moehring and Rawls 1970) have attributed reduced tree growth to increased bulk density.

In contrast to the inner portion, the deposit (outer) portion of skidroads, particularly the berm, was relatively loose. Krag's (1983) studies indicated even looser soils in sidecast. Some compaction by construction and yarding activities was indicated by increased resistance to penetration on the outer track relative to the berm; however, this question was not specifically addressed in this study. The outer portions of the skidroads had, with time, reached a point in which carbon and nitrogen levels were generally on par with the upper, undisturbed mineral soil, or, when calculated on a soil volume basis, were significantly higher in some sites. The generally greater productivity of outer compared with inner portions of skidroads is thus understandable (Smith and Wass 1979, 1980; Youngberg 1959).

High soil density, high resistance to penetration and a low content of fine particles in the inner track are probably sufficient reasons to explain the occurrence of tree growth pattern I (see Table 1) typical of the Russell and Vunder sites. Pattern II, which occurred at the Inlet site, where all skidroad components had low productivity, must be due to a combination of high soil density and nutritional imbalances inherent in alkaline soils (Thorne and Seatz 1955) which adversely affect conifers (Dobbs 1972). Surprisingly, pH values at the Inlet site were high even in the upper mineral soil horizons of the undisturbed soil. We suggest that the better growth in the undisturbed soil was the result not only of lower soil density but also the presence of an intact FH horizon of relatively low pH (5.3) which provided a haven for feeding roots (Dale *et al.* 1955; Harvey 1982). Templeton, the representative site for growth pattern III, in which height growth of trees on the outside of the skidroad was significantly higher than in both the undisturbed and in the inner skidroad, showed no differences in bulk densities though resistance to penetration

was much higher on the skidroad than in the undisturbed soil. Our earlier explanation for this pattern will have to stand, i.e., growth on this steep, high-elevation, north-facing slope was limited by low summer soil temperatures (Smith and Wass 1979). This study showed that skidroad surfaces were warmer in the summer than undisturbed soils — the probable consequence of removal of the insulating humus (Dobbs and McMinn 1973) and a more direct interception of radiation by the flat surface (Geiger 1957). In addition, the FH horizon at the Templeton site was the most acid (pH 3.3) of the three sites possessing organic mats and had the highest C/N ratio (47.2). Humus with these characteristics would tend to have a low rate of decomposition and mineralization (Smith 1965; Keeney 1980), both of which would tend to increase with mixing and increased soil temperature.

The reasons for a lack of any marked growth patterns at the Gold site are not clear. Bulk densities and resistance to penetration tended to be high across the skidroad profile. However, growth rates were only significantly less for one species on the inner track and were significantly higher for a second species in the mid-road than in the undisturbed soil (Smith and Wass 1980). In this relatively dry zone, the compacting and terracing action of the skidroad construction may have increased water availability on the skidroad. Such terracing and contour furrowing have been commonly applied to increase tree seedling survival in various parts of the world (Hall 1969; Post 1974). In addition, the Gold site subsoil had a moderate texture and pH that would tend to favor tree growth.

Conclusions

Rehabilitation of skidroads is bound to be costly and its effectiveness has not been adequately demonstrated. Reduction of skidroad disturbance is thus a prime objective (Johnson and Wellburn 1976; Krag 1980; Froehlich *et al.* 1981; Hammond 1983). Displacement of the upper soil horizons or even of the FH horizon alone should be especially avoided on alkaline soils, i.e., those soils in British Columbia most prevalent east of the Rocky Mountain Trench. Some mixing of surface organic and mineral fractions would be acceptable to the limits of the buffering capacity of the organic matter. These soils are often medium- to fine-textured and are subject to serious mechanical compaction. Cultivation will reduce soil density (McNabb 1981; Voorhees 1983) and should improve growth potential (Andrus and Froehlich 1983). Because of an increasing natural soil density with depth at the inside of skidroads, ripping will be less effective there in reducing the superficial mechanical compaction than on the outside portions of skidroads. In both cases however, ripping should increase water infiltration (Tackle 1962) and leaching and encourage establishment of vegetation. To moderate the high pH levels, surface organic debris from above the skidroad could be spread and crushed on the skidroad but care would be needed to avoid additional exposure of mineral soil. A heavy organic mulch applied along with the seeding or planting of lime-tolerant plants and fertilization with compounds that increase the availability of iron would help restore the original fertility. However, research on the efficacy of such rehabilitative methods on alkaline soils is required.

The subsoils of coarse, acid profiles exposed by skidroad construction would benefit from ripping in concert with fertilizer application and seeding of non-sod forming grasses and legumes to replenish organic matter and nitrogen stocks (Carr 1980).

Because of their better nutrient status, skidroads on medium textured soils in dry zones require less attention. However, ripping would be useful to increase water infiltration and reduce runoff.

Since skidroads cover a significant portion of ground-skidded clearcuts, they are important to future productivity. Establishment of trees on skidroads is therefore essential. In all sites, planting of trees would be most effective on the outside of the skidroad, usually the berm if it is sufficiently stable. Planting at the base of stable sidecast would also be desirable in that root systems would quickly reach buried organic material. Planting on the inside, gouged portions of skidroads will generally not produce an adequate return on the investment. If sufficient natural regeneration is obtained on skidroads, spacing operations should aim at selecting against trees established on the inner half.

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Tables

Table 1. Logging history, biogeoclimatic zone, topographic characteristics and tree-growth pattern of study sites

Site	Years since logging	BGCZ*	Average elevation (m)	Average aspect (deg.)	Average slope (%)	Tree growth pattern**
Russell	18-21	ESSFc	1626	356	44	I
Templeton	23	ESSFa	1532	356	48	III
Inlet	18	ESSFa	1549	274	52	II
Gold	19-20	MSa	1280	094	42	0
Vunder	17-19	IWH	1158	340	59	I

* BGCZ = Biogeoclimatic Zone
ESSFc = Moist Southern Engelmann Spruce — Subalpine Fir Forest
ESSFa = Dry Southern Cordilleran Engelmann Spruce — Subalpine Fir Forest
MSa = Dry Southern Cordilleran Montane Spruce
IWH = Interior Western Hemlock

** Tree growth pattern (from Smith and Wass 1980)
I = Strongly reduced growth on inner skidroad
II = Strongly reduced growth on whole skidroad
III = Strongly enhanced growth on outer skidroad
O = No marked pattern

Table 2. Soil classification, pH and landform descriptions of study sites

Site	Soil classification*	pH at 20- to 60-cm layer	Parent material
Russell	Orthic Humo-Ferric Podzol	4.1 — 4.3	Shallow gravelly loamy sand colluvium over coarse-grained acidic bedrock or compact morainal deposit
Templeton	Podzolic Gray Luvisol	4.1 — 4.3	Shallow to moderately deep gravelly loam to sandy loam colluvium over medium grained bedrock or compact morainal deposit
Inlet	Orthic Eutric Brunisol	7.3 — 7.5	Moderately deep gravelly silt loam morainal blanket over calcareous medium — to fine — textured bedrock
Gold	Orthic Gray Luvisol	5.3 — 5.7	Deep gravelly silt loam to sandy loam morainal deposit
Vunder	Orthic Dystric Brunisol	4.9 — 5.1	Gravelly sandy loam colluvium

* Canada Soil Survey Committee (1978).

Table 3. Average dimensions of skidroad segments

Site	Average width (horizontal)								Depth of cut at inner track	Depth of fill at berm	X-section area of cut (cm^2)
	Inner track	Mid-road	Outer track	Berm	Total surface	Cutbank	Sidecast	Total skidroad			
	cm										
Russell	85	125	71	77	358	140	240	738	58	55	11 151
Templeton	92	86	79	78	335	185	227	747	42	43	12 049
Inlet	82	112	61	81	336	181	309	826	35	63	8 077
Gold	100	139	61	80	380	161	203	744	44	46	11 479
Vunder	97	112	75	79	363	207	330	900	34	77	11 369
Average	91	115	69	79	354	175	262	791	43	57	10 825

Table 4. Total and fine mineral soil bulk densities (g/cm^3) for the 0- to 10-cm and 10- to 20-cm layers in undisturbed soil and skidroad components

Site	Soil fraction	Depth (cm)	Undisturbed soil	Skidroad component			
				Inner track	Mid-road	Outer track	Berm
Russell	Total	0-10	1.11 b*	1.72 a	1.18 b	1.15 b	0.98 b
		10-20	1.07 b	1.76 a	1.26 b	1.24 b	1.02 b
	Fine	0-10	0.77 b	1.39 a	0.86 b	0.86 b	0.70 b
		10-20	0.84 b	1.28 a	0.84 b	0.93 b	0.76 b
Templeton	Total	0-10	1.33 a	1.61 a	1.53 a	1.54 a	1.57 a
		10-20	1.70 a	1.73 a	1.58 a	1.58 a	1.43 a
	Fine	0-10	0.71 a	0.88 a	0.88 a	0.86 a	0.87 a
		10-20	1.01 a	1.03 a	0.93 a	0.95 a	0.72 a
Inlet	Total	0-10	1.01 b	1.48 a	1.33 a	1.33 a	1.32 a
		10-20	1.11 b	1.99 a	1.52 b	1.52 b	1.31 b
	Fine	0-10	0.65 b	1.03 a	1.06 a	0.89 ab	0.88 ab
		10-20	0.70 b	1.45 a	1.22 a	0.85 b	0.88 b
Gold	Total	0-10	1.15 d	1.85 a	1.54 bc	1.77 abc	1.67 abc
		10-20	1.40 b	2.04 a	1.61 b	1.68 b	1.54 b
	Fine	0-10	0.76 b	1.43 a	1.16 a	1.38 a	1.28 a
		10-20	0.83 c	1.58 a	1.22 b	1.32 b	1.11 b
Vunder	Total	0-10	1.40 b	1.73 a	1.76 a	1.79 a	1.66 a
		10-20	1.48 b	2.03 a	1.83 a	2.03 a	1.86 a
	Fine	0-10	0.52 b	0.97 a	1.14 a	1.05 a	0.91 a
		10-20	0.58 b	1.44 a	1.30 a	1.35 a	1.06 a

* Means in each row followed by the same letter are not significantly different at the 0.05 level.

Table 5. A comparison of physical and chemical characteristics of soils at skidroad inner tracks (0- to 10-cm) with equivalent (excavated) depth below the original surface in the upper undisturbed soil (base of cutbank)

Site	Sample location	Bulk density (g/cm³)		Total nitrogen		Organic carbon		Carbonate carbon**	pH
		Total	Fine	(%)	(kg/ha)	(%)	(kg/ha)	(%)	
Russell	Inner track	1.7a*	1.4a	0.09a	1 098a	2.2a	25 824a	NP	4.1a
	Undisturbed	1.6a	1.1a	0.04b	369a	1.1b	8 356a	NP	4.2a
Templeton	Inner track	1.6a	0.9a	0.12a	535a	3.6a	15 602a	NP	4.3a
	Undisturbed	1.6a	0.8a	0.03b	140b	0 7b	3 104b	NP	4.1a
Inlet	Inner track	1.5a	1.0a	0.10a	716a	3.2a	20 515a	1.9a	7.2a
	Undisturbed	1.3a	0.8b	0.07a	378b	1.5a	7 531b	2.0a	7.2a
Gold	Inner track	1.8a	1.4a	0.04a	405a	0.8a	8 231a	NP	5.3a
	Undisturbed	1.8a	1.4a	0.02b	255b	0.3b	4 730b	NP	5.5a
Vunder	Inner track	1.7a	1.0a	0.07a	423a	1.7a	8 898a	NP	5.0a
	Undisturbed	1.6a	0.8a	0.08a	253a	2.7a	5 756a	NP	4.9a

* Within sites, paired means for inner track and undisturbed followed by the same letter are not significantly different at the 0.05 level.

** NP = Carbonate carbon not present

Table 6. Resistance to penetration (penetrometer readings) at the 2.5- and 12.5-cm levels for undisturbed soil and skidroad components

Site	Depth (cm)	Undisturbed soil	Skidroad component			
			Inner track	Mid-road	Outer track	Berm
Russell	2.5	70.6 c*	180.0 a	125.8 b	106.5 b	63.1 c
	12.5	100.0 c	255.8 a	165.4 b	144.6 b	60.0 d
Templeton	2.5	65.8 d	225.0 ab	195.0 b	237.5 a	152.1 c
	12.5	66.7 d	265.4 a	218.8 b	247.5 ab	136.9 c
Inlet	2.5	38.3 d	170.0 a	134.0 b	149.0 ab	76.9 c
	12.5	43.5 d	253.3 a	163.0 b	156.9 b	87.1 c
Gold	2.5	70.5 c	224.1 a	160.9 b	230.9 a	160.7 b
	12.5	70.5 c	238.9 a	172.7 b	197.3 b	116.1 c
Vunder	2.5	49.0 c	124.6 b	112.9 b	176.5 a	113.3 b
	12.5	53.1 c	218.1 a	205.4 a	236.9 a	110.0 b

* Means in each row followed by the same letter are not significantly different at the 0.05 level. Resistance to penetration increases with increasing penetrometer readings.

Table 7. Total nitrogen, organic carbon, carbon/nitrogen ratios and pH for undisturbed FH and mineral soil and for skidroad components

Site	Depth (cm)	Component	Total nitrogen (%)	Total nitrogen (kg/ha)	Organic carbon (%)	Organic carbon (kg/ha)	Carbon/nitrogen ratio	pH
Russell	4-0	FH	0.71	645	23.6	21 757	33.3	3.5
	0-10	Undisturbed	0.09 a*	503 a	2.54 bc	13 718 a	28.1 a	3.8 a
		Inner track	0.09 a	1018 a	2.24 c	25 824 a	25.1 a	4.1 a
		Mid-road	0.13 a	798 a	3.19 abc	20 170 a	25.3 a	4.1 a
		Outer track	0.13 a	846 a	3.79 ab	24 220 a	29.0 a	4.0 a
		Berm	0.15 a	755 a	4.39 a	22 684 a	30.6 a	4.1 a
	10-20	Undisturbed	0.08 ab	490 a	2.04 ab	12 823 b	26.6 a	4.0 b
		Inner track	0.05 b	420 a	1.46 b	12 898 b	31.9 a	4.2 a
		Mid-road	0.10 ab	629 a	2.52 ab	16 456 ab	26.4 a	4.0 b
		Outer track	0.10 ab	708 a	3.06 a	21 269 a	30.6 a	4.0 b
		Berm	0.12 a	684 a	3.34 a	18 862 ab	27.4 a	4.1 ab
Templeton	9-0	FH	0.86	690	39.1	33 831	47.2	3.3
	0-10	Undisturbed	0.08 a	290 b	2.20 a	8 246 b	28.3 a	3.9 b
		Inner track	0.12 a	535 a	3.56 a	15 602 a	29.1 a	4.3 a
		Mid-road	0.10 a	483 a	3.19 a	13 348 ab	29.0 a	4.3 a
		Outer track	0.13 a	607 a	3.99 a	19 029 a	31.5 a	4.1 ab
		Berm	0.12 a	533 a	3.51 a	15 756 a	28.9 a	4.4 a
	10-20	Undisturbed	0.04 a	272 a	1.00 a	6 040 a	22.1 a	4.0 a
		Inner track	0.07 a	355 a	1.94 a	8 456 a	23.4 a	4.3 a
		Mid-road	0.10 a	451 a	2.94 a	13 604 a	28.4 a	4.3 a
		Outer track	0.09 a	475 a	2.52 a	12 387 a	26.6 a	4.2 a
		Berm	0.11 a	364 a	4.85 a	12 644 a	36.1 a	4.2 a
Inlet	7-0	FH	1.01	1395	39.7	52 199	40.8	5.3
	0-10	Undisturbed	0.14 a	556 a	3.73 a	14 957 a	25.9 a	6.9 b
		Inner track	0.10 a	717 a	3.15 a	20 515 a	28.9 a	7.2 a
		Mid-road	0.11 a	873 a	3.11 a	25 643 a	26.5 a	7.1 ab
		Outer track	0.14 a	799 a	4.41 a	25 691 a	32.2 a	7.1 ab
		Berm	0.11 a	620 a	3.30 a	17 581 a	27.8 a	7.2 a
	10-20	Undisturbed	0.11 ab	442 b	2.63 b	8 875 b	20.6 b	7.1 b
		Inner track	0.05 b	442 b	2.63 b	8 875 b	20.6 b	7.1 b
		Mid-road	0.07 ab	643 ab	1.76 b	14 177 b	20.0 b	7.2 ab
		Outer track	0.14 a	796 a	6.31 a	33 405 a	43.4 a	7.1 b
		Berm	0.09 ab	526 b	3.05 b	16 982 b	31.7 b	7.2 ab

(Cont'd)

Table 7. (Cont'd)

Site	Depth (cm)	Component	Total nitrogen (%)	Total nitrogen (kg/ha)	Organic carbon (%)	Organic carbon (kg/ha)	Carbon/nitrogen ratio	pH
Gold	0-10	Undisturbed	0.09 a	431 b	2.40 a	11 088 a	25.4 a	5.4 b
		Inner track	0.04 b	405 b	0.75 b	8 231 a	20.9 a	5.4 b
		Mid-road	0.07 ab	560 ab	1.54 ab	12 416 a	22.4 a	5.6 b
		Outer track	0.06 ab	634 a	1.29 ab	13 988 a	22.1 a	5.8 b
		Berm	0.06 ab	568 ab	1.37 ab	13 380 a	23.3 a	6.3 a
	10-20	Undisturbed	0.06 a	277 b	1.46 a	6 724 c	25.0 a	4.9 b
		Inner track	0.02 b	217 b	0.42 b	4 889 c	23.4 a	5.1 b
		Mid-road	0.05 a	476 a	1.26 a	11 078 b	23.0 a	5.3 b
		Outer track	0.05 a	485 a	1.41 a	14 472 a	30.5 a	5.7 ab
		Berm	0.05 a	386 a	1.30 a	10 018 b	26.9 a	6.1 a
Vunder	0-10	Undisturbed	0.14 a	264 b	3.82 a	6 928 b	26.8 a	5.4 a
		Inner track	0.07 b	423 ab	1.68 b	8 898 ab	22.3 a	5.0 b
		Mid-road	0.08 b	653 a	1.65 b	12 824 ab	20.2 a	5.1 ab
		Outer track	0.10 b	630 a	2.47 ab	15 139 a	24.6 a	4.9 b
		Berm	0.11 ab	518 ab	2.41 ab	10 139 ab	20.8 a	5.1 ab
	10-20	Undisturbed	0.11 a	220 b	3.33 a	5 670 b	28.0 a	5.2 a
		Inner track	0.05 b	561 ab	0.76 b	7 929 ab	16.7 a	5.0 a
		Mid-road	0.08 ab	748 a	1.62 ab	14 113 a	19.2 a	5.0 a
		Outer track	0.06 ab	603 ab	1.39 ab	12 038 ab	21.6 a	5.0 a
		Berm	0.07 ab	429 ab	1.69 ab	8 425 ab	21.3 a	5.0 a

* Means within the same study site/depth columns that are followed by the same letter are not significantly different at the 0.05 level.

Table 8. Stocks of total nitrogen and organic carbon (kg/ha) in the top 20 cm of soil including the FH layer where present

Site	Element	Undisturbed soil	Skidroad component			
			Inner track	Mid-road	Outer track	Berm
Russell	Nitrogen	1 452 a*	1 438 a	1 428 a	1 554 a	1 439 a
	Carbon	43 740 a	38 723 a	36 627 a	45 490 a	41 546 a
Templeton	Nitrogen	1 009 a	890 a	934 a	1 082 a	897 a
	Carbon	42 654 a	24 058 a	26 352 a	31 416 a	28 399 a
Inlet	Nitrogen	1 993 a	1 240 b	1 516 ab	1 595 ab	1 146 b
	Carbon	72 915 a	29 633 b	39 820 b	59 097 ab	34 564 b
Gold	Nitrogen	708 b	622 b	1 036 a	1 119 a	954 a
	Carbon	17 812 bc	13 120 c	23 494 ab	28 460 a	23 399 ab
Vunder	Nitrogen	485 b	984 ab	1 401 a	1 233 a	947 ab
	Carbon	12 598 b	16 828 ab	26 937 a	27 177 a	18 564 ab

* Means in each row followed by the same letter are not significantly different at the 0.05 level.

Table 9. A comparison of some mineral soil characteristics among skidroad and undisturbed components for depths below 20 cm

Depth (cm)	Site	Component	Organic carbon (%)	Total nitrogen (%)	pH	Carbonate carbon (%)
20-30	Russell	Undisturbed	1.41 b*	0.06 b	4.09 a	NP**
		Mid-road	1.12 b	0.04 b	4.13 a	NP
		Berm	3.00 a	0.11 a	4.11 a	NP
	Templeton	Undisturbed	0.72 a	0.04 a	4.13 a	NP
		Mid-road	1.78 a	0.06 a	4.40 a	NP
		Berm	1.64 a	0.16 a	4.07 a	NP
	Inlet	Undisturbed	1.37 a	0.07 a	7.27 a	1.9 a
		Mid-road	1.18 a	0.07 a	7.15 a	1.6 a
		Berm	3.02 a	0.09 a	7.22 a	1.8 a
	Gold	Undisturbed	0.70 a	0.03 a	5.26 a	NP
		Mid-road	0.24 a	0.02 a	5.35 a	NP
		Berm	1.01 a	0.04 a	6.00 a	NP
	Vunder	Undisturbed	1.00 a	0.07 a	4.92 a	NP
		Mid-road	1.09 a	0.05 a	5.03 a	NP
		Berm	0.97 a	0.07 a	5.07 a	NP
30-60	Russell	Undisturbed	0.96 b	0.03 b	4.27 a	NP
		Berm	1.94 a	0.06 a	4.05 a	NP
	Templeton	Undisturbed	0.68 b	0.03 b	4.26 a	NP
		Berm	3.38 a	0.10 a	3.80 b	NP
	Inlet	Undisturbed	1.10 b	0.06 b	7.48 a	3.5 a
		Berm	3.42 a	0.12 a	7.10 a	1.6 b
	Gold	Undisturbed	0.22 b	0.01 b	5.70 a	NP
		Berm	1.22 a	0.06 a	5.85 a	NP
	Vunder	Undisturbed	0.62 a	0.06 a	5.10 a	NP
		Berm	1.33 a	0.07 a	5.08 a	NP

* Within columns of each depth/site combination, means followed by the same letter are not significantly different at the 0.05 level.

** NP = Not present.

Table 10. Comparison of total nitrogen and organic carbon levels in mineral soil at 0- to 10-cm and 10- to 20-cm depths for all skidroad components combined

Site	Depth (cm)	Total nitrogen (%)	Total nitrogen (kg/ha)	Organic carbon (%)	Organic carbon (kg/ha)
Russell	0-10	0.12 a*	854 a	3.4 a	23 225 a
	10-20	0.09 b	610 b	2.6 b	17 371 b
Templeton	0-10	0.12 a	540 a	3.6 a	15 939 a
	10-20	0.09 a	411 b	3.1 a	11 623 b
Inlet	0-10	0.11 a	752 a	3.5 a	22 358 a
	10-20	0.09 a	622 b	3.0 a	18 421 a
Gold	0-10	0.06 a	542 a	1.2 a	12 004 a
	10-20	0.04 b	391 b	1.1 a	10 114 a
Vunder	0-10	0.06 a	556 a	1.2 a	11 750 a
	10-20	0.04 b	585 a	1.1 a	10 626 a

* Within sites, means of depth pairings followed by the same letter are not significantly different at the 0.05 level.

Table 11. Carbonate carbon levels (%) for undisturbed and skidroad components at the Inlet site

Depth (cm)	Undisturbed soil	Skidroad component: Inner track	Mid-road	Outer track	Berm
0-10	1.59	1.91	0.64*	2.10	2.24
10-20	2.01	2.30	0.39*	1.72	2.09

* Significantly less at 0.05 level than other skidroad components when means transformed (natural log (X + 1)).

Table 12. Average soil temperatures (°C) at a depth of 10 cm in undisturbed soil and skidroad components at three times of the day*

Site	Time	Upper undisturbed soil	Skidroad component				Lower undisturbed soil	Air
			Cutbank	Inner track	Berm	Sidecast		
Russell	AM	7.1 abc**	6.5 c	7.3 abc	8.7 a	8.2 abc	7.3 abc	10.2
	Noon	7.6 b	7.0 b	7.9 b	9.8 a	8.2 b	7.9 b	11.6
	PM	7.9 b	7.4 b	8.7 ab	10.1 a	8.3 b	7.9 b	11.2
	Avg.	7.5 bc	7.0 c	8.0 b	9.5 a	8.3 b	7.7 bc	11.0
Templeton	AM	8.2 a	8.8 a	9.7 a	10.8 a	8.2 a	8.6 a	15.6
	Noon	8.6 a	9.8 a	11.6 a	11.9 a	8.5 a	8.6 a	20.2
	PM	8.3 b	9.6 ab	12.2 ab	12.8 a	8.7 ab	8.9 ab	21.4
	Avg.	8.3 b	9.4 b	11.2 a	11.9 a	8.5 b	8.7 b	19.1
Inlet	AM	11.3 ab	12.1 a	11.3 ab	10.5 ab	10.9 ab	9.9 b	9.5
	Noon	11.6 a	12.2 a	11.3 a	11.0 a	11.1 a	10.2 a	15.0
	PM	12.7 ab	14.3 a	13.4 1b	13.4 ab	12.4 ab	11.1 b	17.2
	Avg.	11.8 a	12.8 a	11.9 a	11.5 ab	11.4 ab	10.4 b	13.9
Gold	AM	10.3 b	12.0 a	13.0 a	12.2 a	12.5 a	10.0 b	14.5
	Noon	11.3 b	15.0 a	15.8 a	14.7 a	14.6 a	11.4 b	19.6
	PM	12.2 b	15.5 a	18.0 a	16.8 a	16.0 a	12.3 b	20.5
	Avg.	11.2 b	14.1 a	15.4 a	14.4 a	14.2 a	11.2 b	18.2
Vunder	AM	9.6 c	10.8 b	12.2 a	12.6 a	12.0 a	10.2 bc	13.2
	Noon	9.9 cd	11.1 bcd	12.5 b	14.1 a	12.1 bc	10.4 cd	15.5
	PM	10.4 bc	12.1 bc	14.0 b	16.9 a	12.9 bc	11.3 bc	17.2
	Avg.	9.9 d	11.2 c	12.8 b	14.3 a	12.3 b	10.5 cd	15.3

* Periods of measurement and aspect
Russell — July 7-14/81; 356°
Templeton — Aug. 5-10/81; 356°
Inlet — July 30-Aug. 6/80; 274°
Gold — June 10-19/80; Aug. 19-21/80; 094°
Vunder — July 8-11/80; Sept. 9-11/80; 340°

** Means within rows followed by the same letter are not significantly different at the 0.05 level.